STREAMFLOW AND SEDIMENT YIELD RESPONSES TO FOREST PRACTICES IN NORTH IDAHO

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ABSTRACT

Studies were conducted to evaluate the effects of road construction and patch clearcut harvesting on streamflow and sediment yields from small watersheds and to evaluate the cumulative effects in a larger watershed. The studies were conducted on the Nez Perce National Forest in northern Idaho. The road system, occupying about 2 - 4% of the watershed areas, did not alter annual water yield or peak streamflows. However, following harvesting, there were large increases in annual streamflow from the small watersheds. Increases in streamflow were predominantly during the spring snowmelt period, especially on the rising limb of the snowmelt hydrograph. Harvesting also resulted in large increases in peak streamflows, including the instantaneous peak and the maximum daily streamflow. There was little effect on streamflow during the low flow portions of the year. Modifications in annual streamflow and peak flows were not detectable in the larger watershed with only 6.3% of its area in harvest units and roads.

Sediment yields were increased in both the small watersheds and the large watershed primarily as the result of road construction. Increases in annual sediment yields were highly variable in response to erosion control practices on the roads, time since road construction, annual streamflow, and other watershed characteristics. The largest increases were measured in the subwatershed with the least erosion control practices applied to the roads. Sediment yields were increased threefold for the two years following road construction in the subwatershed. The effectiveness of various erosion control practices on road features is presented. Comparison of increases in sediment yields for the small watersheds and the large watershed suggest that in a period of 7 - 8 years the initial large volumes of sediment produced during the first few years following road construction have moved through the system. However, sediment yields have not returned to pre-disturbance levels after eight years.

Keywords: Streamflow, sediment yield, road erosion, erosion control

INTRODUCTION

In the Northern Rocky Mountain physiographic province of Idaho, Montana, northwest Wyoming and eastern Washington, almost 90% of the streamflow originates from our forest land. This water is important for a variety of uses including irrigation, hydroelectric power, fisheries and recreation. It is important for forest land managers to understand the effects of road building and timber harvesting on erosion, sedimentation, and streamflow. The potential effects on stream channels, aquatic habitat and water quality are concerns which have received much attention in the western United States. This paper discusses the modifications in streamflow and sediment production following road construction and timber harvesting in small headwater watersheds, and the cumulative effects in a larger watershed in north Idaho.

The research was conducted on the Horse Creek Administrative - Research watersheds in the Nez Perce National Forest. The studies have been a joint endeavor between Region 1, the Nez Perce National Forest, and the Intermountain Research Station.

THE STUDY SITE

The 7,730-acre research site is located in T 31 N, R 8 and 9 E, Boise Meridian, in north central Idaho. Horse Creek enters Meadow Creek four miles above its confluence with the Selway River. The area is comprised of two major watersheds, the East and Main Forks of Horse Creek (Figure 1). The East Fork is the control watershed and no road construction or harvesting have taken place within its boundaries. Within the Main Fork drainage are 15 gaged subwatersheds; ten located on the north side of the Main Fork and five on the south side, ranging in area from 54-64 acres. There is one control subwatershed on each side of the Main Fork, subwatersheds 6 and 27. This paper will focus on the effects of road construction and timber harvesting on streamflow and sediment production in subwatersheds 8, 10, 12, 14, 16, and 18, generally south facing watersheds. Selected characteristics o these watersheds are presented in Table 1.

The Horse Creek watersheds are classified as moderately dissected uplands according to Arnold (1975). Elevations range from 4060 ft at the confluence of the East and Main Forks to 6025 feet along the southern divide of the East Fork drainage. The median side slopes for the East and Main Fork drainages are 36% and 31%, respectively.

These watersheds are timber covered with the exception of scattered occurrences of wet bottom land along the major streams and several small meadows and alder glades along the western drainage boundary. The most extensive habitat type in the area is *Abies grandis/Clintonia uniflora*. Other commonly occurring habitat types include *Abies lasiocarpa/Xerophyllum tenax, Thuja plicata/Clintonia uniflora, Abies lasiocarpa/Clintonia uniflora,*

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Abies grandis/Xerophyllum tenax, and *Abies lasiocarpa/Menziesia ferruginea*. Tree species found in substantial numbers include grand fir (*Abies grandis* [Dougl.] Forbes), western red cedar (*Thuja plicata* Donn), western larch (*Larix occidentalis* Nutt.), Engelmann spruce (*Picea engelmannii* Parry), and lodgepole pine (*Pinus contorta* var. latifolia Engelm.). Douglas-fir (*Pseudotsuga menziesii* var. glauca [Beissn.] Franco) and ponderosa pine (*Pinus ponderosa* Dougl.) also occur on some of the south facing slopes.

These watersheds are located in the borderzone of the Idaho batholith, a complex series of related igneous intrusions that contact Precambrian metasedimentary rock of the Belt Super Group. The sedimentary rock was altered by other metamorphic episodes prior to the batholith intrusions. The metasedimentary material s varied and intergrades from quartz-biotite-plagioclase gneiss and schist to biotite-plagioclase quartzite (Greenwood and Morrison 1973).

The soils in the Horse Creek watersheds are inceptisols formed from the weathering of the metasedimentary parent material and modified by deposition of loessial material of volcanic origin. The majority of the area has a mosaic of four soils. The most extensive soils are coarse loamy or loamy skeletal andic dystrochrepts. Second in extent are typic vitrandepts, one medial over loam, and the other medial over loamy skeletal. Both skeletal soils are associated with ridge top positions and the vitrandepts with less steep landscapes.

A typical soil profile has a 3-inch O horizon of partially decomposed twigs and needles overlying a loessial surface horizon ranging from 7-21 inches in thickness. The soil texture generally becomes coarser with depth and the subsoil, extending to depths of 40-60 inches, has a loam to sandy loam texture grading to a gravelly loam to gravelly sandy loam in the skeletal soils. The soils are well drained and have a moderately rapid to rapid permeability.

The climate is influenced by both continental air masses and modified marine air masses from the Pacific Ocean. The summers are warm and relatively dry, with only a few convect. /e storms of short duration and variable intensity. The winter months are wet and cold, although the warmer Pacific air masses can produce some winter melting of the snowpack. Average annual precipitation is about 46 inches (at 5600 feet elevation) and over 70% occurs as snowfall in November through April. Water yield from the Main Fork averages about 18 inches annually with high streamflows occurring in April, May and June in response to snowmelt. The three months of highest streamflow account for about 65% of the annual streamflow and over 90% of the annual sediment production (King 1979a). Streamflow diminishes over the summer and the lowest streamflows usually occur in September or October.

MANAGEMENT TREATMENTS

The first management activity was the construction of midslope logging roads in the summers of 1978 and 1979 (Figure 1). Roads occupy 2.2-4.3% of the subwatershed area (Table 1). Roads were

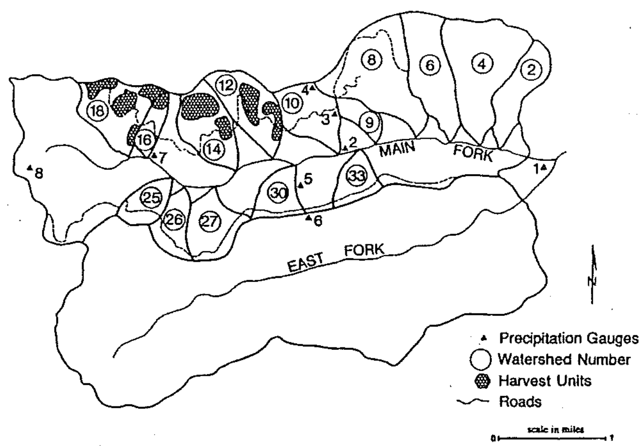

Figure 1.—Map of the Horse Creek subwatersheds nested in the Main Fork drainage showing road, harvest unit and precipitation gauge locations.

Table 1. — Selected characteristics of the Horse Creek watersheds.

Wtsd	Area	Mean elevation[1]	Stream order	Dominant aspect	Road area	Harvest area	Road and harvest area
	Acres	Feet		Degrees	Percent		
6	256	4950	2	166	0	0	0
8	364	4990	2	144	3.7	0	3.7
10	161	4990	2	144	2.6	0	2.6
12	207	5165	2	161	4.1	32.6	36.6
14	154	5235	2	134	2.2	26.9	29.2
16	54	5443	1	198	4.1	20.9	25.0
18	213	5458	2	177	4.3	29.1	33.4
Main	4169	5008	3	86	1.9	4.4	6.3
East	3561	5070	3	68	0	0	0

[1] Average of the maximum and streamgage elevations.

constructed using two design standards. One standard (standard 2) was designed to "fit the topography" and minimize cut and fill heights and for short drainage paths. The other standard (standard 1) was designed for a constant 15 mph hauling speed with less concern on minimizing soil disturbance. Inside ditches were used with both standards to provide road drainage. Within each of the subwatersheds the design standard did not vary. The types of erosion control measures applied to the road features vary between subwatersheds. Fillslope treatments included no treatment (bare slopes), seed (25 lb/ac) and fertilizer (100 lb/ac 20-16-0), hydromulch (1500 lb/ac) and straw mulch (2000 lb/ac) with an asphalt emulsion tackifier (250 gal/ac). Fillslopes receiving the mulch treatments also received the same application of seed and fertilizer. At stream crossings in some subwatersheds slash was machine placed and compacted on the lower portions of the fillslopes to reduce erosion and trap sediment. The cutslope treatments included no treatment, straw mulch with an asphalt emulsion tackifier and hydromulch. Application rates were the same as for the fillslopes and seed and fertilizer were applied in conjunction with the mulches. Traveledway treatments included no treatment, an 8-inch application of gravel, or asphalt. As a result of problems with the asphalt mix, the asphalt was lifted and remixed with gravel and probably functioned similarly to the gravel treatment. Erosion control measures ranged from none in subwatershed 12 to a combination of a graveled traveledway and mulched and windrowed slopes in other subwatersheds.

In the summer of 1981, patch clearcutting took place in four of the six subwatersheds with previous road construction. Areal removal of timber ranged from 21-33% (Figure 1, Table 1) in patches ranging from 9-35 acres. Tractor yarding was done n watersheds 14, 16, and 18. Harvest units in subwatershed 12 were skyline yarded. The units were broadcast burned in the fall of 1981 with the exception of one unit in subwatershed 18, which was burned in the spring of 1982. The hydrologic objective for patch clearcutting on these south facing, "high energy", slopes was to initiate earlier snowmelt and minimize increases in peak streamflow in the Main Fork watershed.

METHODS

Streamflow was measured continuously in the subwatersheds and in the Main and East Forks for the 1975-1986 study period. At the mouths of all watersheds are small debris basins (reservoirs) that trap sediments, primarily sediment in transport as bedload. Volumes of deposited sediments were surveyed annually and core samples taken to determine the bulk density of the deposited sediment, percent organic matter, and particle size distribution. Below the outfall of the debris basins on the subwatersheds, automatic water samplers were used to periodically collect stream water samples. These samples were filtered to determine suspended sediment concentrations of the streamflow. This paper will only discuss sediment yield responses as measured in the debris basins. It is this larger sediment, primarily moving as bedload, that can have a pronounced effect on the channel substrate characteristics and on aquatic habitat.

The study design is typical of most paired watershed studies. There was a "calibration period" of 4-5 years during which statistical relationships (linear regressions) between a control watershed and the other watersheds are determined for selected variables describing streamflow and sediment production. For the 2-3 years following road construction, but before timber harvesting, we compared individual observations in variables with the confidence interval about the calibration regression line. An observation falling outside the 95% confidence interval was interpreted as a significant response to road construction. For those years following both road construction and harvesting, new statistical relationships (linear regressions) between the control watershed and the treated watersheds were determined for selected streamflow and sediment yield variables. Differences between the regressions developed for the calibration period and the treatment period were then tested for significance (Freese 1967; Kleinbaum and Kupper 1978). Average responses in streamflow and sediment yield variables were calculated by comparing the predicted values for the calibration and treatment regressions using the 12-year (1975-1986) average of the variable on the control watershed as the value of the independent variable.

STREAMFLOW RESPONSE

Prior to road construction and harvesting, average annual water yield ranged from 19-25 inches. The portion of annual precipitation that appears as streamflow ranged from averages of 38-41% on subwatersheds 6, 8, 10, 12 and 14 to slightly over 50% on subwatershed 18. The difference between annual precipitation and streamflow, an estimate of losses primarily due to evapotranspiration, ranged from 23 inches on subwatershed 18 to between 27 and 28 inches on the other subwatersheds. Removal of forest vegetation in road construction and harvesting, thereby reducing evapotranspiration, has a large potential to increase annual streamflow.

The effects of the midslope logging roads on selected streamflow variables for the six subwatersheds have been previously reported (King and Tennyson 1984). Forest roads occupying about 2-4% of the subwatershed area had no significant ($P>0.05$) effects on annual streamflow, maximum instantaneous streamflow or the date of its occurrence, minimum daily streamflow or the streamflow equalled or exceeded 75% of the time. However, we did detect a significant ($P<0.05$) increase in the streamflow equalled or exceeded 25% of the time for one subwatershed and a decrease in the streamflow equalled or exceeded 5% of the time for another subwatershed. Midslope logging roads can intercept subsurface flow and reroute flow in their ditch system, altering the magnitude and timing of streamflow. The location of the road and its effects on altering subsurface flow paths result in variable effects between subwatersheds. The degree of road construction in these headwater basins had no detectable effect on annual water yield or peak streamflow, but higher road densities may result in measurable responses in these streamflow variables. Harr (1976) reports in studies of storm flow responses to forest practices in western Oregon that large peak flows appear to be increased only when greater than about 12% of the watershed area is severely compacted by roads, skidtrails and landings.

Annual water yield was significantly increased following road building and harvesting on all four of the subwatersheds that had both road construction and harvesting. The increase in annual water yield was proportional to the area in roads and harvest units. Increases in annual average water yield ranged from 13% on subwatershed 16-29% on subwatershed 12. Average increases, prorated to the area in harvest units and roads, ranged from 12.0 inches in 1982 to 15.9 inches in 1983. Average increases in annual water yield over the 1982-1986 treatment period were 14.1 inches, prorated to the area in roads and harvest units. This large increase in annual water yield represents about a 50% reduction in evapotranspiration losses on subwatersheds 12, 14, and 16 and about a 60% reduction on subwatershed 18.

Understanding when these large increases in onsite water production appear as streamflow is just as important as knowing the magnitude of the increase. Figure 2 illustrates the monthly distribution of average streamflow for the calibration and treatment periods. The largest increases in monthly streamflow occur during the snowmelt period of April and May. The clearcuts in subwatershed 12 were generally steeper and had a more southerly aspect, resulting in higher solar radiation inputs during the winter and spring months. On subwatershed 12, snowmelt was advanced and large increases in streamflow also occurred in March. In subwatershed 12 the date at which half the annual streamflow was produced was advanced about 8 days. Increases in streamflow are predominantly on the rising side of the snowmelt hydrograph with little change in monthly streamflow on the recession side of the hydrograph. These road and harvest treatments had little effect on streamflow during the low flow portions of the wateryear. Total September through January streamflows were slightly increased on subwatersheds 14, 16 and 18, but this increase was only significant ($P<0.01$) on subwatershed 12 with a 20% increase. During the recent prolonged drought in Idaho, various individuals and groups have voiced concern about timber harvest causing reductions in streamflow during portions of the year. Studies of the effects of conventional timber harvesting practices on streamflow in the snow dominated zones of the Intermountain West, such as those in Horse Creek, have not reported reductions in streamflow during lowflow portions of the wateryear. The increases in streamflow are generated during the portion of the year when ample streamflow is available for most uses. Harvesting timber to specifically augment water supply for irrigation or domestic use will probably need to done in conjunction with storage facilities.

Increases in short duration peak flows occurred on all four of these subwatersheds (King 1989). Instantaneous peak flows increased significantly ($P<0.10$) in subwatersheds 14, 16, and 18, averaging 34-36% (Table 2). The 15% increase in instantaneous peak flow in subwatershed 12 was not significant ($P>0.10$). This smaller increase in instantaneous peak flow in subwatershed 12 may be a result of earlier initiation of snowmelt and shallower snowpacks during the period when peak flows were generated. Increases in the maximum daily streamflow were significant ($P<0.05$) on all four subwatersheds and ranged from 3 -87%. The smallest increase was again measured in subwatershed 12. I also evaluated the effects of treatment on the 3, 7 and 15 consecutive days of highest streamflows during spring snowmelt (Table 2). With only one exception significant increases were detected ($P<0.05$). Generally increases became smaller for longer periods of consecutive days of highest streamflow and increases became larger with increasing average elevation of the subwatersheds.

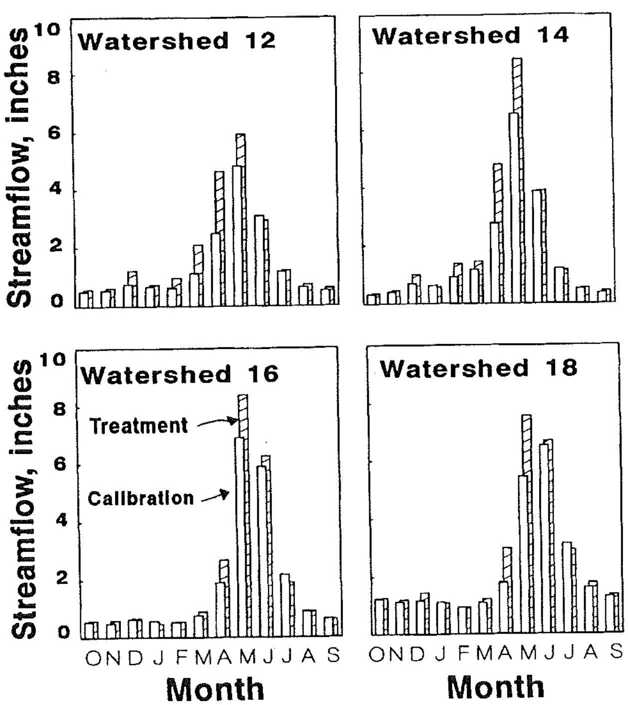

Figure 2.— Monthly distribution of streamflow for subwatersheds 12 and 18 for the calibration period and following road construction and harvesting

Table 2.—Average increases in streamflow variables indexing high streamflows for the Horse Creek subwatersheds.

Streamflow Variable	Subwatershed 12	14	16	18
	percent increase			
Instantaneous peak	15[1]	35	36	4
Maximum daily	34	50	74	87
3-day	36	58	90	104
7-day	32	54	76	92
5 day	23	46	321	53

[1] Increase not significant ($P>0.05$).

Increases in these shorter duration high flows represent a substantial increase in stream energy and the capacity to transport sediment. Bedload sediment transport can be expressed as a relationship with streamflow:

$$Q_s=aQ_w^b \qquad [1]$$

where Q_s is the bedload sediment transport rate, Q_w is the stream discharge and a and b are coefficients. For the Horse Creek subwatersheds discussed in this paper, the b coefficient ranged from 2.1-3.0 during wateryears 1975 and 1976. Thus, a small increase in peak streamflow represents a large increase in bedload sediment transport capacity. Often, over half the annual bedload production occurs in the 7-10 days of highest flows. With increases in short duration peak flows following harvesting, it is important that activities that might destabilize the channel be avoided. Activities such as removal or addition of woody debris in the channel, in the presence of increased peakflows, have the potential to accelerate channel erosion.

In the Main Fork watershed with only 6.3% of its area in roads and harvest units, we did not detect changes in annual streamflow, instantaneous peak flows or maximum daily streamflows. Often procedures or methods used to estimate the streamflow response from forest practices focus on 3rd order and larger watersheds. Hydrologically important streamflow responses in headwater basins may be overlooked. Results of this study suggest the need for a conservative approach to scheduling harvesting in headwater basins. This is especially true in situations where channels might be sensitive to increases in peak flows.

SEDIMENT RESPONSES

Prior to any management activities these forested watersheds had relatively low sediment yields, with annual sediment yields, equalled or exceeded 50% of the time, ranging from 7.3 yd^3 mi^{-1} for the East Fork to 65.4 yd^3 mi^{-1} for subwatershed 16 (Figure 3). Sediment production varies substantially between years and is highly correlated with annual streamflow. For a given wateryear there were substantial differences in per unit area sediment yields for these adjacent watersheds. For example, in 1975, sediment production ranged from 11.7 yd^3 mi^{-2} in subwatershed 6 to 82.96 yd^3 mi^{-2} in subwatershed 16. There was a strong negative exponential relationship between sediment yield and watershed area (Figure 3). The smaller watersheds in Horse Creek typically have steeper gradients, are more actively downcutting their channels and have higher sediment yields.

Following road construction, there were significant increases in annual sediment yields for all six subwatersheds. Field observation of erosion and sediment flow paths suggest that the roads are producing the vast majority of the sediment and not the harvest units. Buffer strips between the harvest units and the streams were generally effective in trapping sediments from the harvest units. Table 3 gives the sediment yield increases for the treatment period through 1986, the road design standard and the erosion control practices. Sediment production measured at the mouths of these small watersheds was highly variable and ranged from an average of 0.45 to 7.11 yd^3 yr^{-1}. Sediment yield is a function of many variables, including watershed size, the number of stream crossings, the time following road construction, streamflow characteristics, and erosion control treatments on the roads. Sediment yields measured at the mouths of these watersheds are an integrated response to a variety of upstream and upslope processes and differences are not solely a result of differences in management practices. Figure 4 shows the increases in sediment yields following road construction from two subwatersheds of similar size and with a similar percentage of area in roads, but with different road erosion control practices. Subwatershed 12, with bare cutslopes and fillslopes and an unsurfaced traveledway had the largest increases in sediment yields of all subwatersheds. Sediment production was increased over 3X for the first two years following road construction and averaged 2.05X through 1986. In contrast, subwatershed 18, with hydromulched cutslopes and fillslopes, placement of slash along he fillslopes at stream crossings, and a graveled traveledway had an average increase in sediment production of 1.39X through 1986. In subwatershed 18 the largest increase in sediment yield

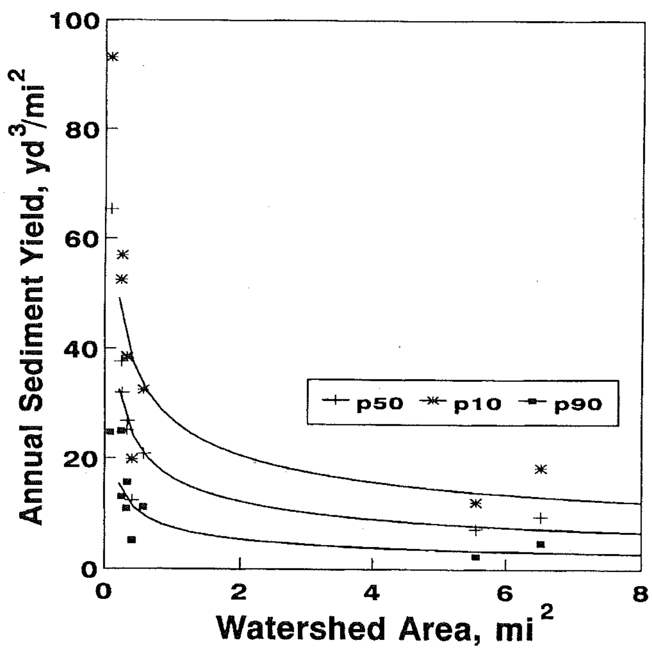

Figure 3.—Watershed area versus annual sediment yield for three levels of probability of occurrence.

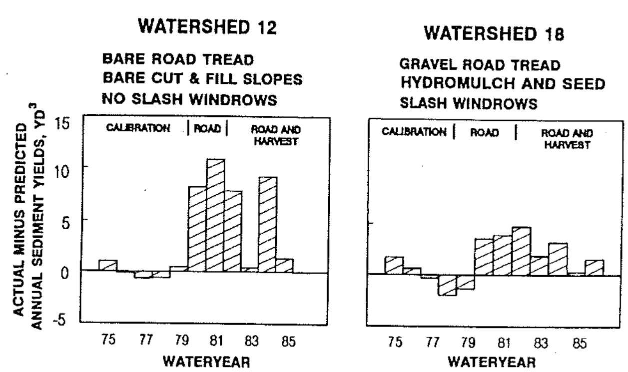

Figure 4.—Increases in annual sediment yields following road construction for subwatersheds 12 and 18.

Table 3.—Sediment yield increases for the six subwatersheds in Horse Creek that had midslope logging roads.

Watershed	Increase in Sediment Yield through 1986 Total	Average	Road standard	Erosion Control Treatments[1] Fillslopes	Cutslopes	Traveledway
	yd^3	yd^3/yr				
8	35.3	4.41	2	S/A	S/A,SB	G
10	24.9	3.56	2	S	N	N
12	49.8	7.11	1	N	N	N
14	3.2	0.45	2	S/A	S/A,SP	G
16	32.9	4.12	1	H	H,SP	G
18	23.3	2.91	1	H	H,SP	G

[1]S/A = straw mulch with asphalt tackifier, seed, fertilizer
H = hydromulch, seed, fertilizer
S = seed mixture, fertilizer
N = no treatment
SP = slash placement on fillslopes near stream crossings
SB = straw bales place at toe of fillslopes near stream crossings

was 1.76X in 1980. From a land managers view point it is meaningful to look at the effectiveness of individual erosion control measures on the roads in addition to the integrated effects at some downstream location.

The most prevalent form of erosion on the fill slopes was the development of rills and gullies caused by drainage of concentrated flow from the road traveledway (King 1979b). Typically, initial erosion rates are very high and exponentially decrease over time as the surface becomes armored with larger particles and as revegetation occurs (Megahan 1984; King 1984). This was especially true on the fillslopes. For example, on one section of road about half the total fillslope erosion measured over a 2-year period occurred the first summer and fall. Much of the erosion occurred in response to rain events before the fillslopes were mulched. The seed, straw mulch and hydromulch treatments were not very successful in controlling erosion caused by concentrated runoff and the effectiveness of these three treatments were not statistically different. Erosion reductions were 46-58% on fillslopes with vertical heights of less than 20 feet and 24-30% on fillslopes with heights ranging from 20-40 feet.

The placement and compaction of slash on the fillslopes was more effective than seeding and mulching in reducing erosion. These windrows of slash, placed 100 feet on either side of stream crossings, reduced erosion and trapped sediment from the traveledway and the upper portions of the fill slopes. Reductions in sediment production from the fillslopes over a 3-year evaluation period were 75-85% (Cook and King 1983). An additional evaluation of the erosion control effectiveness of hand placed slash on fillslopes in Horse Creek was conducted using applications of artificial rainfall on small fillslope plots. Measured erosion reductions from this treatment were 88% (Burroughs and King 1985). Typically road contracts requiring placement of slash do not reflect higher costs, since this slash would have to be disposed of via end hauling and burying or burning. With the increasing use of hydraulic excavators to construct forest roads, windrows of slash can be constructed concurrently with road construction, providing immediate erosion control.

Bank sloughing during saturated conditions is a dominant erosion process for the cutslopes (King and Gonsior 1980). About 80% of the cutslope erosion took place from November to mid- June and only 20% in the summer and early fall. On these 0.75:1 cutslopes the hydromulch treatment did not significantly educe erosion. Over the 3-year measurement period the straw mulch treatment reduced cutslope erosion by 32-47%. In a demonstration area outside of these subwatersheds, a cutslope constructed with a gentler slope (1.25:1) and straw mulched show little evidence of surface erosion and the resulting stand of grass was very uniform. On road sections approaching stream crossings, cutslope heights are often reduced and a section of through-fill is created over the stream channel. In these areas, laying back the cutslopes to a gentler gradient will increase the effectiveness of any mulch treatment and not appreciably increase slope lengths. In these Horse Creek watersheds, long-term sediment production from the road prism will be largely from the cutslopes and the road ditch system (Burroughs and King 1989) due to steeper gradients and less regrowth of vegetation on the slopes as compared to the fillslopes.

There were no direct measurements of traveledway erosion at the Horse Creek sites. However, Burroughs and King (1985) used applications of artificial rainfall on unsurfaced and graveled roads to evaluate the effectiveness of a 4-inch layer of 1-1/2 minus gravel in controlling erosion. Surface erosion on a 8% gradient road was reduced by 79%. This site had similar soils to the Horse Creek site and these results should be applicable to the Horse Creek roads.

Much of the fillslope erosion was generated by concentrated flow from the traveledway. On the graveled road sections the layer of gravel was not spread entirely across the entire width of the subgrade. Often runoff collected in wheel ruts on the outside edge of the subgrade not surfaced with gravel or it collected along the outside edge of the lift of gravel. Spreading gravel completely across the subgrade can reduce fillslope erosion by minimizing rutting and the collection of runoff water along the lift of gravel. The use of temporary berms to protect fills from road drainage until vegetation becomes established or insloping the road in areas where eroded fill material has a high potential to reach streams are other means to minimize fillslope erosion.

A more complete discussion of the effectiveness of a variety of road erosion control techniques is provided in Burroughs and King 1989).

While we were unable to detect any changes to streamflow at the mouth of the Main Fork watershed following road construction and harvesting, we did measure increases in annual sediment yields in the Main Fork. Figure 5 illustrates the increases in annual sediment yields for the Main Fork watershed. In 1979, the first complete wateryear following road construction, significant increases were not measured in the Main Fork. Retention of sediment in the debris basins on the subwatersheds delays sediment responses in the Main Fork by one year. There were significant increases in both the slope and intercept between the calibration and treatment period regressions, suggesting larger sediment yield increases in years of higher annual streamflow. increases ranged from 3.1 yd^3 during the year (1985) of lowest streamflow to 67.1 yd^3 during the highest year of streamflow 1984). For the 1980-1986 treatment period, total sediment yield increases were 168 yd^3, an average of a 32% increase.

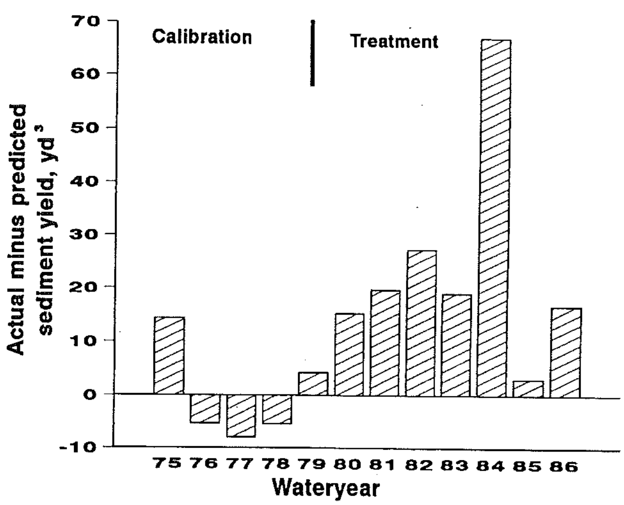

Figure 5.—Increases in annual sediment yields for the Main Fork Horse Creek.

To assess to what degree the increased sediment production from the subwatersheds has moved through the Main Fork watershed, I compared the cumulative increases in sediment yields for the Main Fork with the cumulative increase in sediment yields for all the six roaded subwatersheds over the period 1980 through 1986 (Figure 6). In 1980, approximately 40% of the increase in sediment measured from the subwatersheds was measured in the debris basin on the Main Fork, suggesting a large proportion of the material was being temporarily stored in the Main Fork channel. This percentage increased over time and through 1986 about 97% of the increase in sediment yield from the tributaries was measured at the mouth of the Main Fork. This would indicate that the initial large quantities delivered to the Main Fork channel the first few years after construction moved through the system in a period of 7-8 years. However, even after eight years from the initial road construction activities, sediment yields have not been reduced to pre-disturbance levels.

SUMMARY

Timber removal on 25-37% of the area of small headwater watersheds increased annual water yield by an average of 14.1 inches, prorated to the area in harvest units and roads. Increases in streamflow occurred during the spring snowmelt period, especially during the rising portion of the snowmelt hydrograph. These forest practices also resulted in large increases in short duration peakflows, greatly increasing the sediment transport capacity of these small streams. The cumulative effects of these activities on streamflow in the Main Fork, with only 6.3% of its area in roads and harvest units, were not detectable.

Annual sediment yields increased in both the small headwater subwatersheds and in the Main Fork primarily as a result of road construction. Increases in average annual sediment yields ranged from 0.45 - 4.41 yd^3 yr^{-1} for the subwatersheds and 24 yd^3 yr^{-1} or the Main Fork. After 8 years from the initial road construction, increased sediment production was still occurring in the Main Fork. There was some indication that the initial large volumes of sediment produced the first few years following road construction had moved through the system.

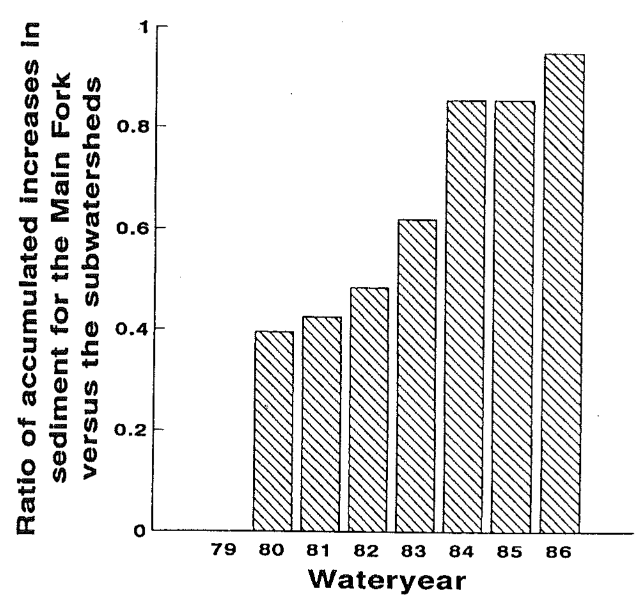

Figure 6. —The ratio of sediment yield increases for the s and the Main Fork of Horse Creek.

Erosion control practices on roads can be effective in reducing road erosion and stream sedimentation. Slash placement on the fillslopes and gravelling the traveledway were two of the most effective erosion control treatments. Of special importance is prevention of any surface runoff on the traveledway from being diverted unto fillslopes, especially until the slopes become vegetated.

LITERATURE CITED

Arnold, J. F. 1975. A source book of information for the Idaho Batholith. Ogden, UT: USDA Forest Service, Intermountain and Northern Regions, Intermountain Forest and Range Exp. Sta. 290 pp.

Burroughs, E. R., Jr. and J. G. King. 1985. Surface erosion control on roads in granitic soils. *In:* Jones, E. B.; Ward, T. J., eds. Watershed management in the eighties: Proceedings; 1985 April 30-May 1; Denver, CO. [New York]; Amer. Soc. Civil Engineers: 183-190.

Burroughs, E. R., Jr. and J. G. King. 1989. Reduction of soil erosion on forest roads. Gen. Tech. Rep. INT-264. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 21 pp.

Cook, M. J. and J. G. King. 1983. Construction cost and erosion control effectiveness of filter windrows on fillslopes. Res. Note INT-335. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 5 pp.

Freese, F. 1967. Elementary statistical methods for foresters. Agric. Handb. 317. Washington, DC: USDA Forest Service. 87 pp.

Greenwood, W. R. and D. A. Morrison. 1973. Reconnaissance geology of the Selway-Bitterroot wilderness area. Pamphlet 154. Moscow: Idaho Bureau of Mines and Geology. 30 pp.

Harr, R. D. 1976. Forest practices and streamflow in western Oregon. Gen. Tech. Rep. PNW-49. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Exp. Sta.

King, J. G. 1979a. Water quality characteristics of the Horse Creek watersheds in north central Idaho. Res. Tech. Compl. Rep., Project A-051-IDA. Moscow: Idaho Water Resources Research Inst. 118 pp.

King, J. G. 1979. Fillslope erosion from forest roads. *In:* Proceedings, 34th meeting, 1979 October 3-5; Boise, ID. Paper 79-404. St. Joseph, MI: Amer. Soc. Agric. Engineers. 11 pp.

King, J. G. 1984. Ongoing studies in Horse Creek on water quality and water yield. Tech. Bull. 435. New York: Nat'l. Coun. of the Paper Industry for Air and Stream Improve: 28-35.

King, J. G. and L. C. Tennyson. 1984. Alteration of streamflow characteristics following road construction in north central Idaho. Water Resources Research. 20(8): 1159-1163.

King, J. G. 1989. Streamflow responses to road building and harvesting: a comparison with the equivalent clearcut area procedure. Res. Paper INT-401. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 13 pp.

Kleinbaum, D. G. and L. L. Kupper. 1978. Applied regression analysis and other multivariable methods. Duxbury Press, North Scituate, MA. 556 pp.

Megahan, W. F. 1984. Road effects and impacts-Watershed. *In:* Proceedings, forest transportation symposium; 1984 December 11-13; Casper, WY. Lakewood, CO: USDA Forest Service, Rocky Mountain Region, Engineering Staff Unit; 1985: 57-97.

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